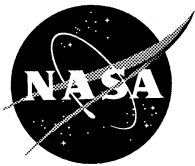


NASA/CR—2002-211332



# Processing of IN-718 Lattice Block Castings

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# PROCESSING OF IN-718 LATTICE BLOCK CASTINGS

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## Abstract

Recently a low cost casting method known as lattice block casting has been developed by JAM Corporation, Wilmington, Massachusetts for engineering materials such as aluminum and stainless steels that has shown to provide very high stiffness and strength with only a fraction of density of the alloy. NASA Glenn Research Center has initiated research to investigate lattice block castings of high temperature Ni-base superalloys such as the model system Inconel-718 (IN-718) for lightweight nozzle applications. Although difficulties were encountered throughout the manufacturing process, a successful investment casting procedure was eventually developed. Wax formulation and pattern assembly, shell mold processing, and counter gravity casting techniques were developed.

Ten IN-718 lattice block castings (each measuring 15-cm wide by 30-cm long by 1.2-cm thick) have been successfully produced by Hitchiner Gas Turbine Division in Milford, New Hampshire, using their patented counter gravity casting techniques. Details of the processing and resulting microstructures are discussed in this paper. Post casting processing and evaluation of system specific mechanical properties of these specimens are in progress.

## 1. Introduction

Cellular metals are an attractive class of materials with extremely low density and outstanding combination of mechanical, thermal and acoustic properties. They offer a large potential for lightweight structures, energy absorption and thermal management structures.

Lattice block materials (LBM) are a family of cellular structural materials that derive their mechanical performance from their structure of highly ordered internal triangles acting as an interlocked truss system. The concept behind LBM can be applied to wide variety of parent materials such as engineering metals and ceramics. The proprietary manufacturing methods developed by JAM Corp. can be applied in most existing production facilities. Choosing appropriate element proportion (length to width ratio) and angles allows the LBM matrix density to be specified. Additionally, the matrix can be configured with layers of different geometries and densities. Overall shape be created by machining the LBM or by specifying custom production methods. JAM Corp has successfully demonstrated LBM of various engineering materials such as Al-base, Fe-base, Be-base and Cu-base alloys by a low cost investment casting technique. Cast LBM can be furnished in variety of shapes and curves and made with integral face sheets (Ref. 1).

Alloy IN-718 was developed by the International Nickel Company in the 1950's and is currently used in cast, wrought and powder forms. It is the most used alloy both GE and Pratt & Whitney aircraft engines for many critical applications such as disks, cases, shafts, blades, stators, seals, supports, tubes and fasteners. This alloy has both business and technical characteristics that have enabled continued growth of its application base: (1) free license to manufacture has allowed a large material supplier base to evolve (2) favorable precipitation kinetic provides substantial processing advantage, particularly welding and castability; and (3) relative manufacturing ease has permitted multiple manufacturing process and products to develop over the years. Investment casting is extensively used for cost-effective manufacturing aircraft components (Ref. 2).

Despite the enormous success of IN-718 several significant challenges must be addressed if this alloy is to retain its predominance well into 21st century. Chief among these is the need to improve the temperature capability and time dependent fracture behavior. Numerous attempts have been made over the past 20 years to improve temperature capability of IN-718 for existing applications through chemistry modification involving Co and Ta additions but none has been entirely successful (Ref. 3). In addition to the temperature capability, advanced applications such as Ultra-Efficient Engine Technology (UEET) initiated by NASA Glenn Research Center for the next generation of the transport system require very light weight alloys to achieve high fuel efficiency and range. The concept is dictated by the tradeoff between performance and manufacturing cost. For attainment of minimum weight of a component four important factors, such as material selection, utilization of shape, topology optimization and multi functionality are essential (Ref. 4). Short comings in material density can be circumvented by designing shaped components that optimize load capacity. The topologies can be used to achieve load capacity at yet lighter weights, as exemplified by truss structures and honeycomb panels. The truss topology (such as lattice block) has the further benefit that its open spaces can be used to impart functionalities in addition to load bearing, such as cooling, whereupon the extra weight of an additional component normally needed to provide that function can be saved. Therefore NASA Glenn has initiated research to investigate lattice block castings of high temperature Ni-base superalloy such as IN-718 for lightweight nozzle applications.

## **2.0 Experimental**

NASA Glenn requested JAM Corp., to supply total of 10 LBM castings, 5 with and 5 without face sheet of the size 15-cm wide by 30-cm long by 1.2-cm thick. The patterns of this size and shape were prepared by JAM Corp., using their injection molding process.

### **2.1 Pattern Making**

There have been a number of challenges in initiating the production of investment cast superalloy LBM. The bulk of earlier difficulties resulted from the injection and assembly of the wax patterns. To address these problems a number of steps were taken ultimately leading to a full pattern making capability at JAM Corp. In the final analysis it was easier for JAM Corp. to figure out how to produce the patterns than it was to try and teach the foundries to do it for this application. The primary advantage of making the patterns at the JAM Corp. was the ability to experiment with dozens of different waxes, settings and other variables such as gating and mold

venting. Following assembly of the wax pattern completely, shell molds were produced at Hitchiner gas turbine division (Milford, New Hampshire) using their automatic shell building technique.

## **2.2 Hitchiner Counter Gravity Investment Casting Process**

Hitchiner Counter gravity casting processes (Ref. 5) were used to cast LBM of IN-718. These processes are particularly suitable for thin castings. Based on casting equipment and environment, used Hitchiner has at least three variations of the basic counter gravity casting process (hereafter called Type I, Type II and Type III). As these processes are still under patent review, we cannot describe the details of these processes. All three variations were tried to cast lattice blocks of IN-718. So far we have made 10 LBM castings of IN-718 using Hitchiner's counter gravity investment casting process.

The basic Hitchiner counter gravity technique originally developed in mid 1970's uses vacuum to provide the driving force to fill the castings. Entraining air into the molten alloy during stirring can adversely affect the filling of mold. Ladle pouring of the metal common to sand, permanent mold and conventional investment casting can easily introduce turbulent flow as the metal plunges from ladle into the down sprue of the gating system. Hot metal is placed in a vacuum chamber with a fill pipe extending out the bottom. The fill pipe entrance is lowered beneath the certain surface of the molten metal and a vacuum is applied to the casting chamber. Atmospheric pressure on the melt forces the metal to rise up the fill pipe and enter the mold. By tailoring the vacuum profile to the casting geometry and alloy, the result is metal drawn from the clean undisturbed zone under the melt surface filling the cavity in quiescent manner. A hot mold near the solid temperature for the material helps achieve the cell sizes.

## **3.0 Results and Discussions**

### **3.1 Pattern Making**

The design of the castings and supply of wax patterns was provided by the JAM Corp. Figure 1 is a photograph of wax pattern that was the end result of about 4 months of continuous experimentation. A glue that bonds the wax compound was identified and a prototype gluing system was built to automate assembly. It is also found that the gate areas can be "stitched" together with a soldering iron. The hot iron creates holes through the multiple wax layers, which then fill with molten wax and harden. The techniques developed will be generally useful for all LBM investment casting patterns. Since pattern making appears to be the technology bottleneck, and the production bottleneck as well, this is where work has been focused. A twelve layer ceramic shell was prepared at Hitchiner, Inc., and used in all the casting trials. This shell is particularly suitable for the counter gravity processes.



Figure 1: Photograph of an assembled wax pattern for investment casting of IN-718.

### **3.2 Hitchiner Counter Gravity Casting Process**

The main advantages of this process over the conventional casting process are the following: (1) Cleaner metal with less slag and non metallic inclusions (2) Increased control of fluid flow minimizing turbulence (3) controlled grain structures in thin sections (4) increased efficiency. Several intricate and complex shaped gas turbine components such as combustor liners of Ni-base super alloys have been manufactured cost effectively by the counter gravity process.

### **3.3 Casting Results**

Each casting measured 15-cm wide by 30-cm long by 1.2-cm thick. The average ligament diameter was 1.58 mm with a 0.045 mm standard deviation and maximum/minimum values were 1.62 mm and 1.523 mm, respectively. For the five castings with a face sheet on one side, the average face sheet thickness was 0.074 mm with 0.0025 mm standard deviation and maximum/minimum values were 0.077 mm and 0.066 mm, respectively.

Figure 2 shows the photograph of IN-718 casting produced by Type I counter gravity process. Figure 2 indicates clearly that the metal did not fill the mold completely because this process used lower molten temperature and lower rate of rise. In order for the Type I process to be suitable for this casting the casting fill out has to be improved. So the Type I process requires the fastest rate of rise and high temperature in order to achieve the required fill.



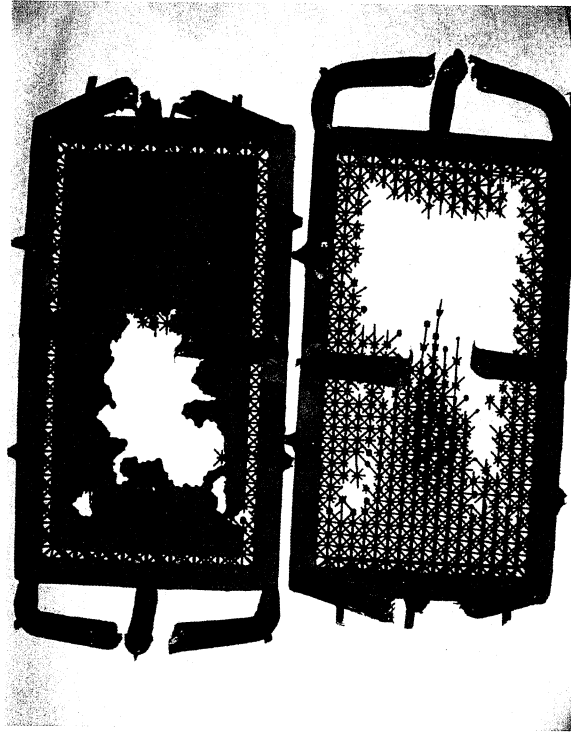


Figure 2: Photograph of IN-718 LBM casting produced by Type I counter gravity process.

Type II Counter gravity Process: The results from Type II trials, which employ very high molten metal temperature and a fast rate of rise, are shown in Figure 3. The Type II process also did not produce defect free castings.

The Type III counter gravity process had fewer problems in filling the lattice castings (Fig. 4). The remaining six castings were produced by Type III process. However, the ring gate around the lattice was pulling the casting during solidification and caused distortions.

### **3.4 Lattice Casting Defects**

Out of 10 castings, only 6 castings produced by the Type III process had few defects. The remaining 4 castings had numerous defects such as partially filled ligaments and non metallic inclusions (Fig. 5). The industrial practice for producing IN-718 ingot is to use triple melting consisting of vacuum induction melting followed by electro slag refining (ESR) and vacuum arc remelting (VAR). The size of nonmetallic inclusions is drastically reduced during electro slag refining. The number of non metallic inclusions and gaseous inclusions is reduced during vacuum arc remelting. In the present investigation, the IN-718 used as a charge for melting was produced by vacuum induction melting only. The large sized inclusions present in the molten metal might have entered the thin section of LBM casting and thus created a defect. Other defects observed were (2) Excess metal (Fig. 6); (3) Non fill (Fig. 7); (4) Shell fill (Fig. 8); (5) Metal entering through gate (Fig. 9) and (6) Metal entering through flash (Fig. 10). These defects can be minimized or totally avoided by choosing a proper counter gravity process and processing parameters for alloy IN-718.

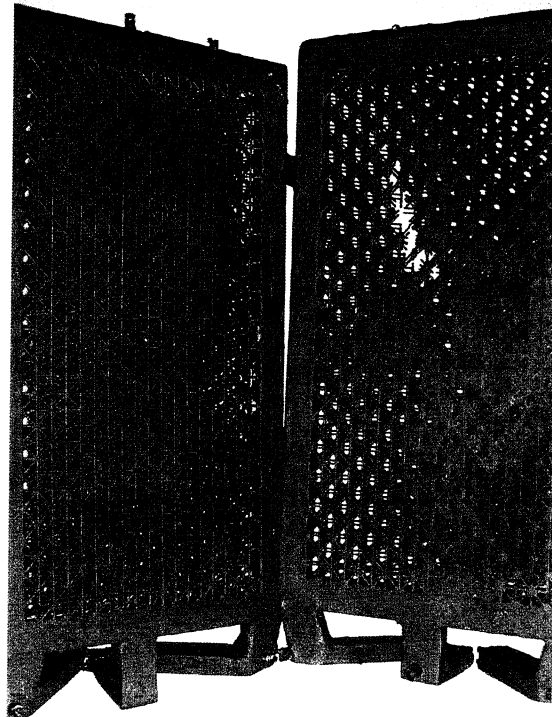


Figure 3: Photograph of IN-718 LBM casting produced by Type II counter gravity process.

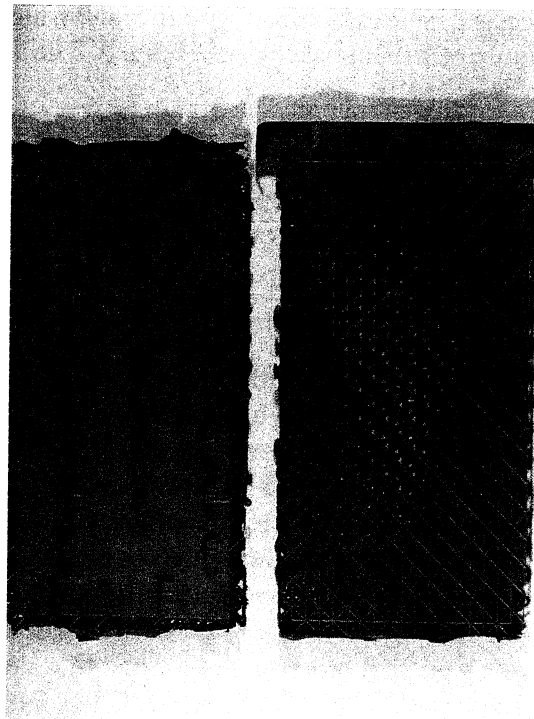


Figure 4: Photograph of IN-718 LBM casting produced by Type III Hitchiner process.

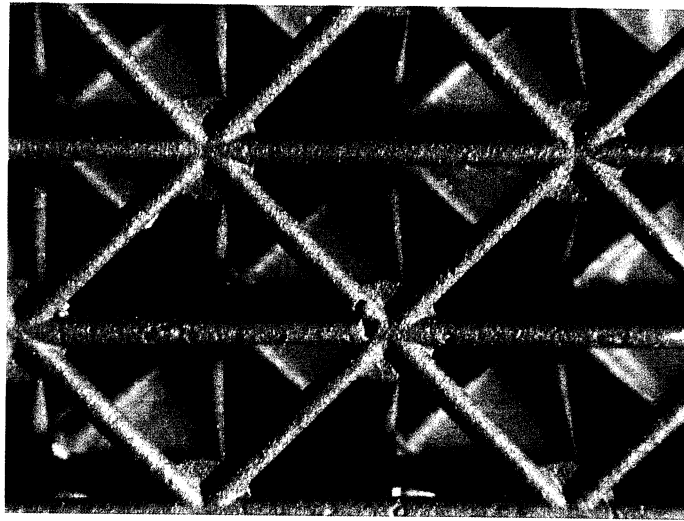


Figure 5: Photograph of partial filling of ligaments due to nonmetallic inclusions.

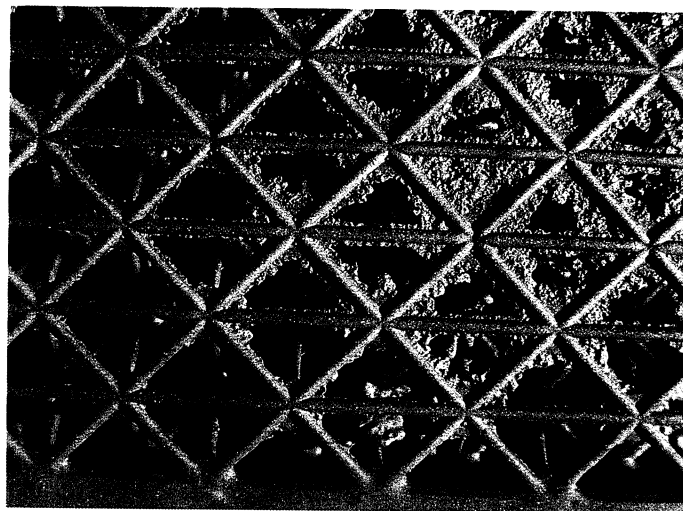


Figure 6: Photograph of excess metal.

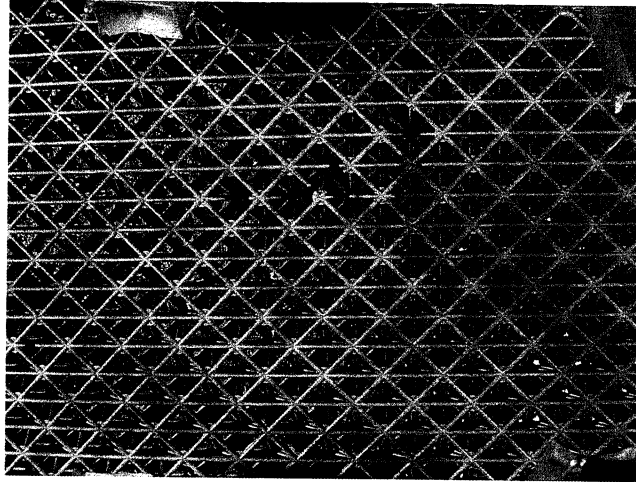


Figure 7: Photograph of nonfill.

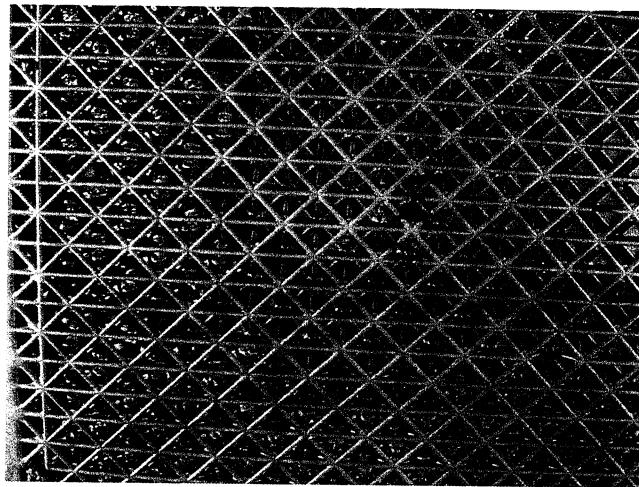


Figure 8: Photograph of shell fill.

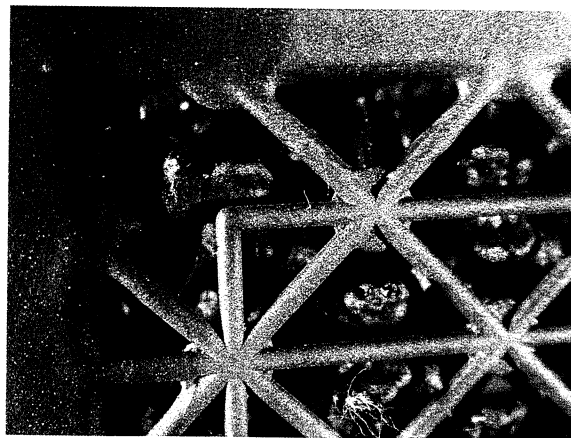


Figure 9: Photograph of metal entering through gate.

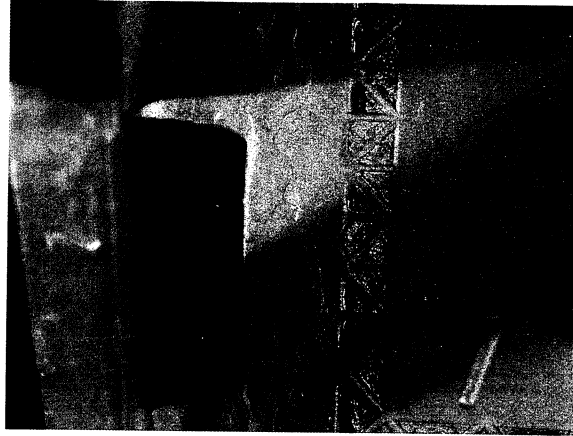


Figure 10: Photograph of metal entering through flash.

### **3.5 Microstructure of as-cast IN-718 LBM**

The nominal composition of alloy IN-718 is given in Table 1.

Table 1: Nominal Composition (in wt.%) of IN-718

Ni	Fe	Cr	Mo	Nb	Ti	Al	C	B
balance	18	18	3	5	1	0.5	0.04	0.004

The phases reported in IN-718 are Nb, TiC, TiN, delta, Laves,  $\gamma$ ,  $\gamma''$ ,  $\alpha$ Cr, sigma and  $M_6C$ . The major strengthening phases in IN-718 are the  $\gamma''$  and  $\gamma'$  phases which produce coherency strains in the  $\gamma$  matrix. Basically the cast IN-718 is heavily segregated and consists of two compositions: the dendrites which are high in Fe, Cr and Ni while interdendritic areas are rich in Nb, Ti and Mo. The Nb content in the dendrite can be as low as 2 percent while the interdendritic regions are rich in Nb (>12 percent) (Ref. 6). The high Nb content causes the formation of NbC, TiN, and Laves phases in the interdendritic regions. The homogenization cycle is the key to producing a uniform material. Typical as-cast microstructures of IN 718 LBM are shown in Figures 11(a) and (b). The SEM image in Figure 11(a) shows a light and dark patterns whose size depends on the cooling rate. The light areas are high in Nb and the dark areas are low in Nb. Figure 11(b) shows the same sample with variety of phases present in the interdendritic areas. The Laves islands are dark due to their response to the sample preparation while delta plates,  $\gamma'$  and  $\gamma''$  phases are light.



Figure 11(a): SEM micrograph of LBM cast IN-718.



Figure 11(b): Higher magnification.

#### **4.0 Summary and Conclusions**

Lattice block castings of IN-718 (15-cm long by 30-cm wide by 1.2-cm thick ) have been successfully produced. Initially there were numerous problems in making the pattern of our design. This was overcome by using a new wax having higher strength and lower thermal expansion. Hitchiner counter gravity processes were used to cast the lattice blocks of IN-718. Type I and Type II counter gravity processes did not yield a good quality casting. However, the Type III counter gravity process yielded a very good quality with few defects. The main defects in lattice block castings are partial filling of ligaments due to nonmetallic inclusions, excess metal, nonfilling of the lattice, shell filling of the lattice and metal flashing at the gate. These defects can be minimized by carefully choosing the type of process and processing parameters. In fact, more castings of IN-718 with and without face sheets have now been produced successfully using Type III counter gravity processing. These castings will be evaluated for mechanical performance, as well as their response to hot isostatic pressing heat treatment.

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